On the Szentirmai Transformation

Szentirmai[1] has described some network equivalences which proved to be very useful in the design of crystal filters. Several authors[2–5] have subsequently provided alternative techniques for carrying out the same transformations. This correspondence proposes a new calculation method, which appears to be considerably simpler (conceptually as well as numerically) than its predecessors.

The simplified network equivalences are shown in Figs. 1, 2, and 3. They correspond to different distributions of the two loss-poles in the two stopbands, as indicated in the captions. It is significant that all branches in all the lattice networks resonate at one of the specified loss-poles and anti-resonate at the other.[6] This way the transmission zeros are obtained without difficulty and the design equations become more tractable.

The transformation of Fig. 1[4,5] is initiated by splitting C_{1p} into two parallel capacitors (C'_{1p}, C''_{1p}), and C_{2s} into two series capacitors (C'_{2s}, C''_{2s}). Capacitors C'_{1p} and C'_{2s} are selected to make the impedance containing L_1, C_1, and C'_{1p} a constant multiple of that consisting of L_2, C_2, C'_{2s}. Then the simple equivalence of Fig. 4 is applicable. The resulting design equations are given in Fig. 5.

The formulas for the circuit of Fig. 2 are obtained by choosing the resonant and anti-resonant frequencies of all lattice branches as ω_3 and ω_1, respectively. The remaining six unknowns (e.g., C_s, C_{ap}, C_{bp}, C'_s, C_p, t) are easily obtained by equating Z_{11} at $\omega = \omega_3, \infty$; Z_{22} at $\omega = \omega_1, \omega_3, \infty$; and finally Z_{12} at an arbitrary $\omega(\neq 0, \omega_1, \omega_3, \infty)$, for the two configurations. The resulting design equations are displayed in Fig. 6.

Finally, the circuits of Fig. 3 can be obtained from those of Fig. 2 by an $LP \rightarrow HP$ and a duality transformation. Hence, the design formulas are simply related to those of Fig. 2. They are also included in the flow chart of Fig. 6.

The capacitors C'_p, C'_s are always negative; C_p and C_s also frequently turn out to have negative values. In such cases they may be absorbed in the lattice branches.

Note that the potential equivalence[7] of the left-hand structures of Figs. 1, 2, and 3 can be seen by applying the simple transformations shown in Fig. 7.[8] These can also be used to demonstrate in advance that it is always possible to find a lattice realization such that the loss-poles are the critical frequencies of the lattice branches (regardless of the location of these loss-poles). The only exception is the special case $\omega_1 = \omega_3$;[9] for this, the trivial transformations of Fig. 8 apply.

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[1] G. Szentirmai, "On the realization of crystal band-pass filters," *IEEE Trans. on Circuit Theory (Correspondence)*, vol. CT-11, pp. 299–301, June 1964.

[2] K. Yen Cheng, "Synthesis design of cascaded lattice crystal band-pass filter," *1964 Proc. Allerton Conf. on Circuit and Systems Theory.*

[3] J. A. C. Bingham, "A calculation method for Szentirmai's modified lattice circuit," *IEEE Trans. on Circuit Theory (Correspondence)*, vol. CT-12, pp. 284–285, June 1965.

[4] J. Lang and C. E. Schmidt, "Crystal filter transformations," *IEEE Trans. on Circuit Theory (Correspondence)*, vol. CT-12, pp. 454–457, September 1965.

[5] E. Christian and E. Eisenmann, "Considerations for the design of crystal filters," *1965 Proc. Allerton Conf. on Circuit and Systems Theory.*

[6] In general, loss-poles are produced by the intersection of the lattice branch-reactances. Here, the equivalences are defined so that these "intersections" occur only at the zeros and poles of the reactances.

[7] Apart from unimportant capacitive pads.

[8] J. E. Colin, "Mutation des circuits provoquant les pointes d'affaiblissement infini dans les structures de filtres en échelle," *Cables et Transmission*, vol. 12, pp. 10–22, January 1958. The appearance of negative element values here is irrelevant, since the transformation of Fig. 4 is not restricted to positive elements.

[9] This was pointed out to the authors by H. J. Orchard.

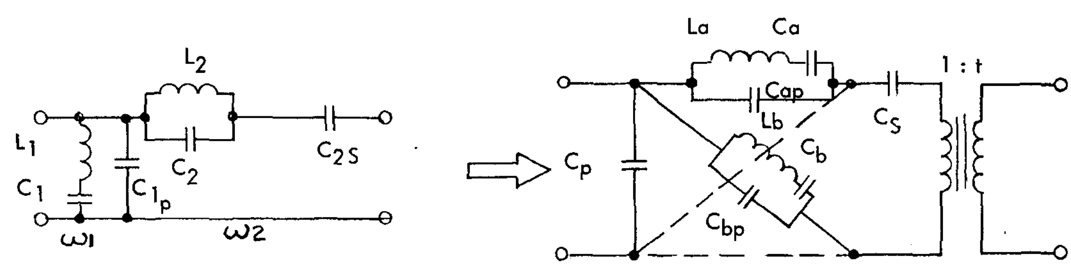

Fig. 1. $\omega_1(\omega_3)$ in lower (upper) stopband.

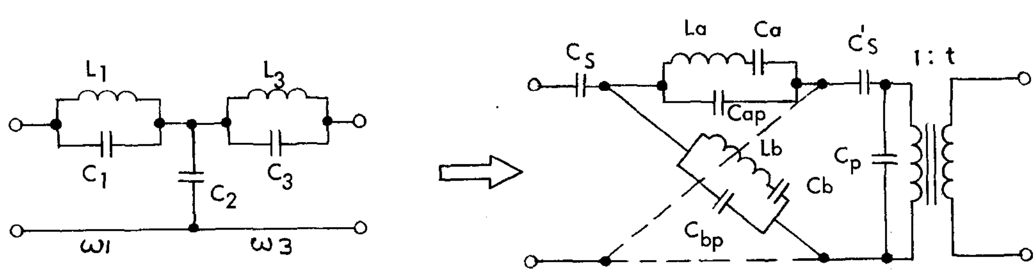

Fig. 2. ω_1, ω_3 in upper stopband, $\omega_1 > \omega_3$.

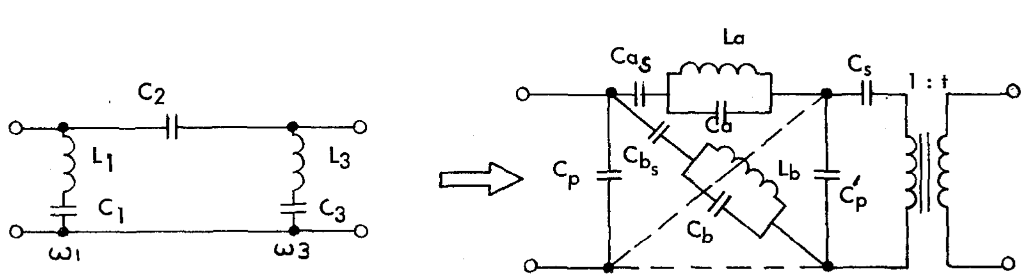

Fig. 3. ω_1, ω_3 in lower stopband, $\omega_1 < \omega_3$.

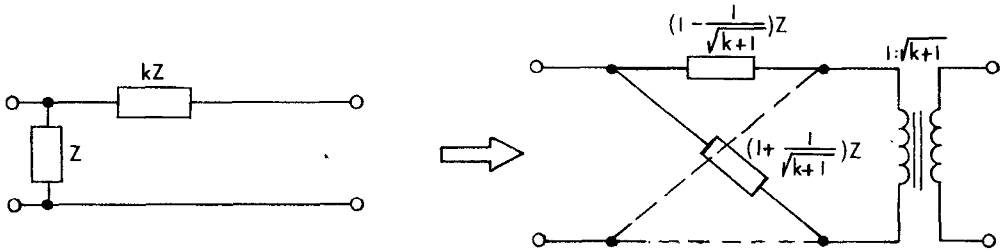

Fig. 4. *L*-section to lattice transformation.

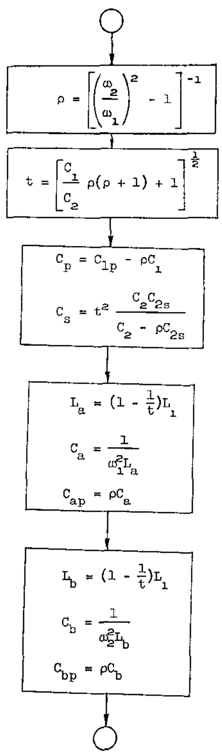

Fig. 5. Flow chart of computations for the equivalence of Fig. 1.

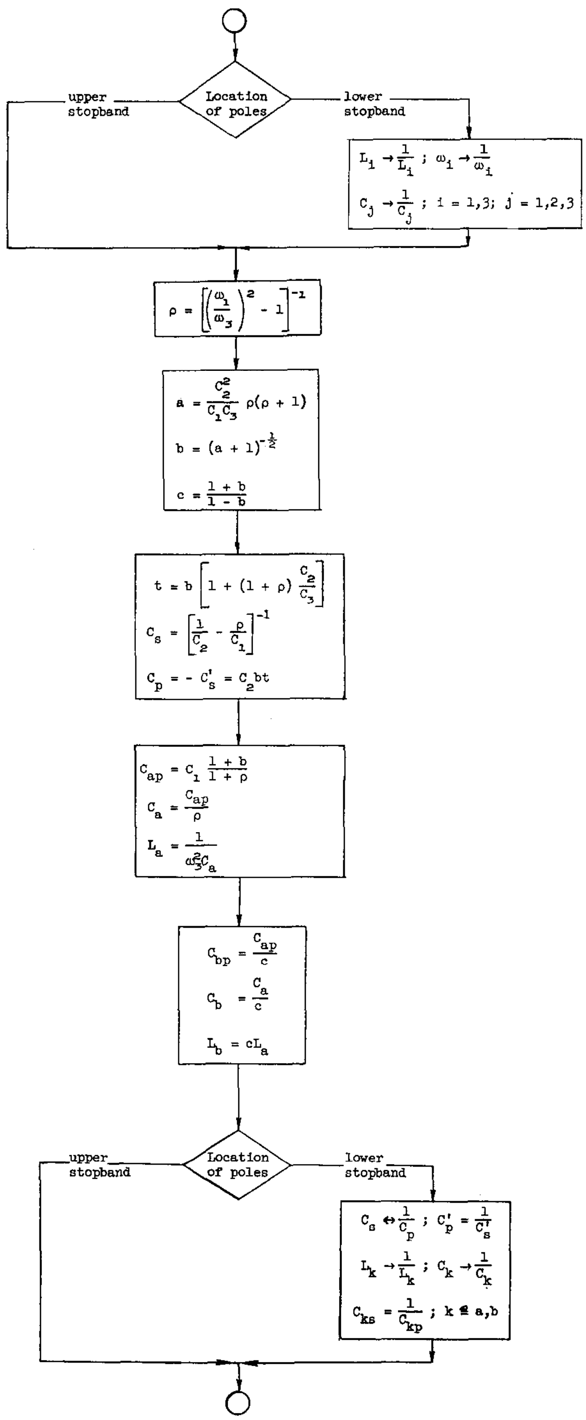

Fig. 6. Flow chart of computations for the equivalences of Figs. 2 and 3.

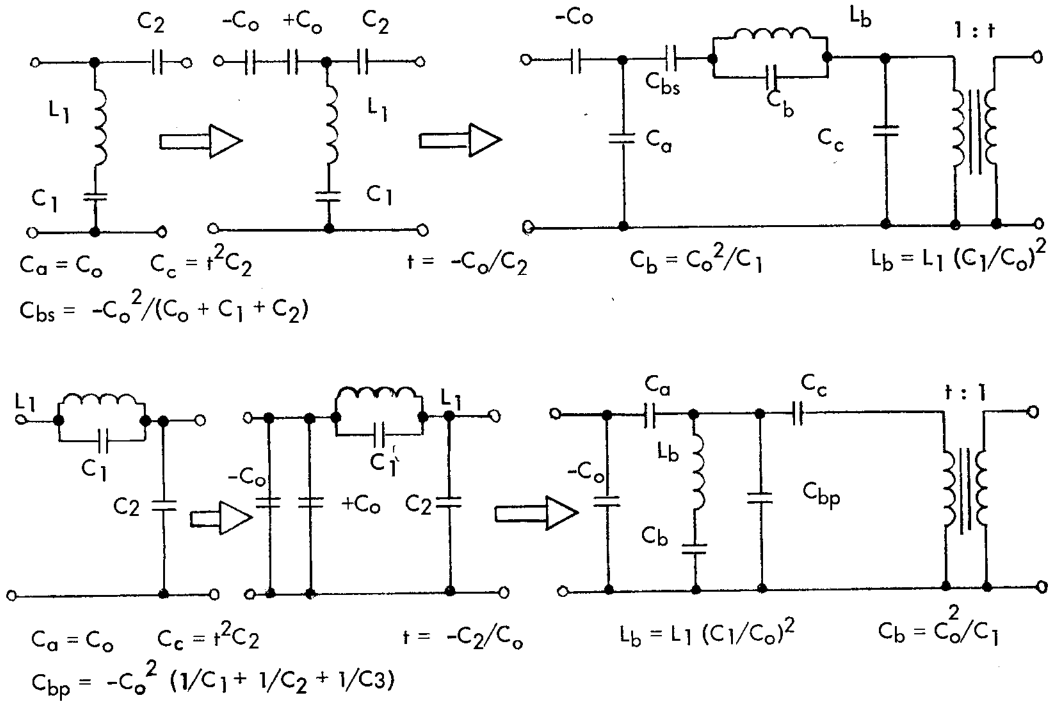

Fig. 7. Ladder network transformations.

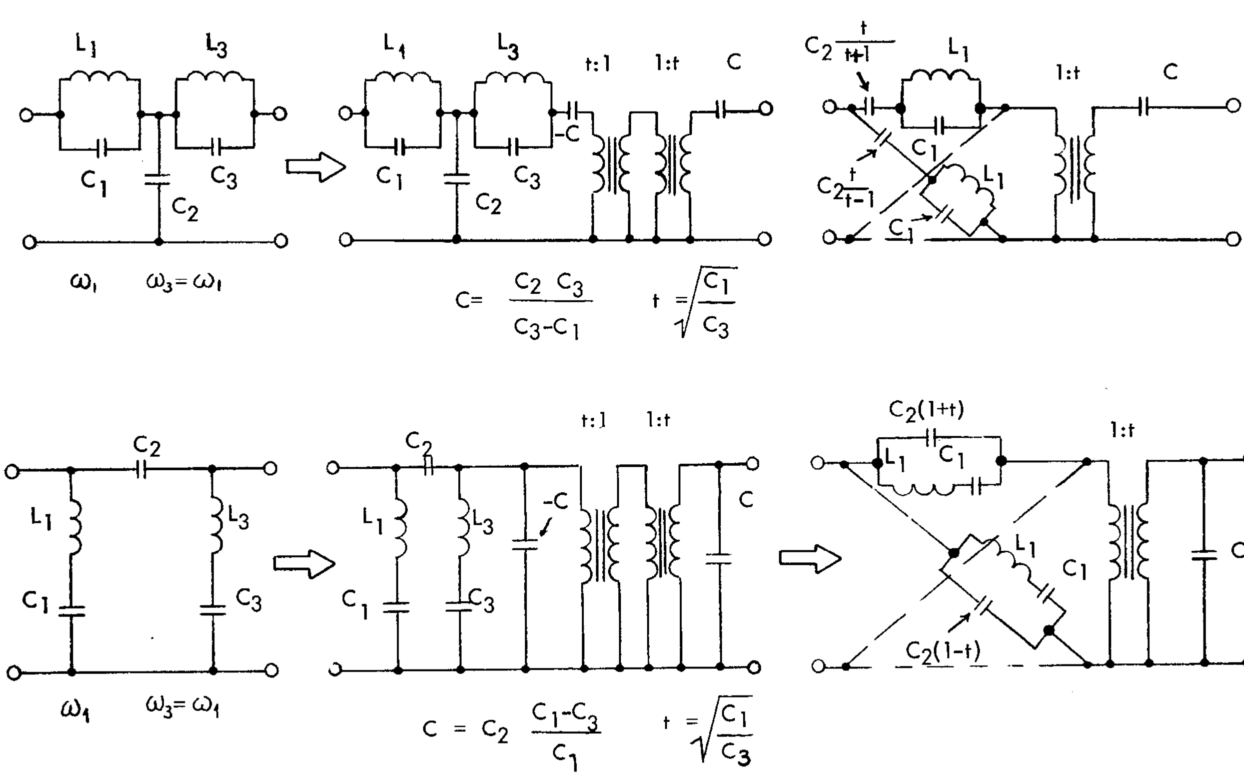

Fig. 8. Transformations for $\omega_1 = \omega_3$.

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